Renewable and Sustainable Energy Reviews 31 (2014) 520–530

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Implications and future direction of greenhouse gas emission mitigation policies in the building sector of China

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ARTICLE INFO

Article history:
Received 2 May 2013
Received in revised form
15 December 2013
Accepted 29 December 2013
Available online 20 January 2014

Keywords:
Greenhouse gas
Emission
Mitigation
Building
Policy
China

ABSTRACT

A common starting point in assessing greenhouse gas (GHG) reduction policy implications in the built environment is to look at industry specific policies. This paper addressed the glaring gap between national all-economy policy options that actually determine industry-specific programs, and their downstream impacts and implications to the building and construction sector. National carbon policy schemes were organised into two basic types: indirect pricing mechanisms, and direct pricing mechanisms. Their features and comparative strengths and limitations were critically reviewed under a common framework, drawing from a wide body of literature. The status of the application of the GHG reduction policies in China was reviewed. A green building case is studied to quantitatively present the effectiveness and deficiencies of the current GHG mitigation policies in the building sector of China, and their implications to a building's life cycle. Based on China's current status of the policy system, this paper identifies the future direction of building's GHG mitigation policies of China. Policies directly aiming to GHG mitigation in the building sector should be implemented in holistic and comprehensive pathway, to balance the costs and benefits of the stakeholders for the promotion of building GHG mitigation technologies.

Contents

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http://dx.doi.org/10.1016/j.rser.2013.12.023

1. Introduction

Global warming is considered as one of society's greatest and most important challenges today because of the potential range and severity of impacts to communities, and to our natural and built environments [1]. Unmitigated greenhouse gas (GHG) emissions would cause further warming and adverse impacts not just in this century but also beyond. Thus, a wide range of policy and technological solutions are being studied or adopted by many national governments and organizations to reduce GHG emissions. Many countries, including China, have made GHG mitigation commitment and set quantitative reduction targets [2]. Considering the high speed of economic development, the Chinese government has made a GHG emission reduction commitment by 2020, which is measured in GDP. To ensure the realization of the emission mitigation target, multi activities have been processing in China. Specific objectives for GHG mitigation has been brought into the Twelfth Five-Year Plan (2011–2015) of China, such as establishing emission auditing system, certification system for low carbon products, emission trading market etc. [3,4]

About 33% of all energy related GHG emissions globally are from energy consumption in commercial and domestic buildings [5–7]; this contribution increases if the GHG emissions from the manufacturing and transport of construction products (i.e. the "embodied carbon" in products and buildings) are also considered. The cost efficiency of GHG emissions mitigation or carbon abatement efforts is considered to be the highest or most favourable in the building sector compared to other sectors [8,9]. With more than 44 billion square meters of existing building stock [10], it is estimated by the government that about 30 billion square meters of new buildings will be added in China by 2020 [11]. The building sector has one of the fastest growing energy consumption trends today and that extends into the future in a business-as-usual scenario. As a matter of fact, achieving the emission mitigation potential is especially paramount in China [12].

But for the large part, the building and construction industry has been mostly reactive to national GHG emissions policy debates or setting. The exception to this situation is the proactive efforts of industry or market-based building organizations that promote voluntary green building ratings (e.g. in the US, UK, Australia, etc.) and also advocate GHG mitigation policies and initiatives (e.g. [13]). An industry that has both significant contribution to GHG emissions and huge potential for mitigation could contribute more positively to public policy debates if there is better understanding of the downstream or industry-specific implications of high-level, national or all-economy GHG mitigation policy options. The Chinese Ministry of Housing and Urban-Rural Development (CMOHURD) promised that newly built green and sustainable building will reach no less than 65% in cities by the end of 2015 [14]. Promoting green and sustainable buildings has been a priority of the national GHG emission reduction plan of China.

Many barriers exist for applying sustainable technologies, such as high upfront investment costs, long pay back periods, difficulty in quantifying the benefits of sustainable building etc. [15–17]. Policies from the government are needed to remove the barriers caused by external diseconomy of GHG emission reduction. Recent researches looked at the potential of the adoption of technologies in new buildings in different US cities or regions (e.g. [18]), sophisticated modelling of consumer adoption of incentives or rebates in the residential sector (e.g., [19]), mitigation opportunities in developing countries using existing mechanisms of the United Nations Framework Convention on Climate Change (UNFCCC) [20], appropriate political measures to improve the energy performance of existing dwellings in Korea [7] and the effectiveness of different policy instruments considered best-practice examples from about 30 countries and country groups [6,21]. These studies provide useful and practical insights of the implications of building sector specific policies and initiatives. The researches about GHG mitigation policies in the building sector of China are relatively much fewer. Barriers, policies and appropriate technologies of building's energy efficiency in China were discussed in previous researches [22–26]. The possibility and implementation method of some specific policy instrument were analysed, such as clean development mechanism (CDM) [12,27] or energy performance contracting (EPC) [28]. However, the implications and effectiveness of the current policy system aiming to GHG mitigation in the building sector of China are unknown to date.

This paper aims to review first the broad GHG mitigation policy options and features in a framework and context relevant to the building sector, and then China's policies related to building's GHG mitigation. A green building case is studied to quantitatively present the effectiveness and deficiencies of the current GHG mitigation policies in the building sector of China. Based on China's current status of the policy system, this paper identifies the future direction of building's GHG mitigation policies of China.

2. GHG mitigation policy options

2.1. General types and classifications

The plethora of national or jurisdictional (e.g., state or province) policies and programs that aim to reduce GHG emissions are categorized and presented in Table 1. Some of the schemes have been implemented only in a specific sector, some are implemented across a number of sectors, and others are applied across the whole economy. For simplicity, these policies can be classified further into two primary approaches:

- Indirect pricing ('Regulations and incentive instruments' in Table 1);
- Direct pricing ('Direct pricing instruments' in Table 1).

Table 1
A taxonomy of GHG emissions mitigation policies.

Policy types	Contents and examples
Regulations	
Laws and regulations	Energy/water/other resources conservation, renewable energy production, GHG emission mitigation, climate change
Government goals and plans	Government commitment, national plan, technology development plan
Regulatory rules	Construction process, building operation, government procurement, specific rules for public buildings or infrastructures
Mandatory standards and codes	Building design, building construction, building appliances
Incentive instruments	
Economic incentives	Subsidies, rewards, financial privilege, energy performance contracting, taxes (not for GHG emissions, such as fuels)
Informative incentives	Voluntary certifications or labelling, technology promotion, information provision, pilot and demonstration, advertising, education
Direct pricing instruments	
Carbon taxes	Domestic, tariff
Emission trading scheme	Cap-and-trade, clean development mechanism

The indirect pricing approach includes (a) actions by government such as regulations, or by the market/industry such as technology deployment, (b) any voluntary schemes, whether initiated or administered by either government or industry, under some incentive mechanisms. Regulations are normally taken as those that are legally required and, thus, enforceable. On the contrary, incentive instruments are optional. The direct pricing approach can be a direct carbon tax, some version of an emissions trading scheme (ETS) or a system that starts with a carbon tax that then transitions into an ETS after a set period of time (e.g. [29]). The indirect pricing policies are usually directed toward a particular economic sector, such as the building sector. However, the direct pricing policies are usually cross-sectoral implemented. There are alternative ways of classifying GHG mitigation policies but for the purpose of this paper, the schemes will be referenced under these two primary classifications.

2.2. Description

In this section, the main schemes according to prevalence and maturity in terms of implementation are presented, starting with indirect pricing approaches (regulations, voluntary and incentive instruments) and then with direct pricing approaches (carbon tax and ETS).

2.2.1. Regulations

Being one of the most basic functions and expectations of government, every jurisdiction maintains and administers a set of regulations on a range of topics. In one form, a scheme will mandate minimum allowable performance (a more performance based approach); in another, a scheme will state the acceptable "solutions" from the set of product choices available to consumers (a more prescriptive approach) [30]. Examples include legal statement(s) mandating, licensing or banning particular technologies or production techniques used by firms operating in the domestic economy [31] or adopting specific existing technologies [32], regulation about hazardous compounds, and permit requirement for environmentally hazardous activities [33]. Regulations are preferred when there are dangerous substances, where monitoring is difficult or best available technique requirement can be easily identified [34].

2.2.2. Incentive instruments

Incentive instruments have various forms, but their general aim is to motivate consumers and/or industry to change their behaviours by providing (a) information and examples of successful implementation [35], or (b) a certification or approval label to reflect better quality and/or greater value, or (c) some economic incentives (Table 1). Government may use incentives to directly entice end-users and industry). Economic incentive instruments involving government support include capital subsidies grants, subsidized loans and special funds, e.g. developing new technology related to energy efficiency and the purchase of energy efficient appliances or buildings directly [36]. Informative incentive instruments include voluntary certification and labelling, voluntary and negotiated agreements, education, information campaigns, detailed billing and disclosure programs, etc. [6]. Incentive instruments can make a significant contribution if the governments or policy makers design them well and utilise them to legitimize, interact and reinforce other policy instruments [37].

2.2.3. Carbon tax

A carbon tax is a fixed price scheme where the price of GHG emission is set by the government in the form of a direct tax, and this price drives individuals and businesses to decide how much they will reduce their emissions [38]. A direct tax for individuals may or may not be included. For example, in Australia, the proposed scheme is set for three years and spares individuals, households and small businesses from being taxed directly [29]. The plan is to use the revenue raised to provide tax cuts and increased benefits to households, support jobs in the most affected industries, and provide funding to support large-scale (supply-side) and end-user adoption of renewable energy systems and implementation of energy efficiency measures and technologies. A study of Productivity Commission [39] did not find a similar economy-wide carbon tax scheme, but some governments have taxed directly the use of fossil fuels.

2.2.4. Emission trading scheme

An ETS is a floating price scheme, where the government sets the quantity of emissions ("caps"), and permits to emit are issued up to that amount [38]. The permits are tradeable between businesses and so the market sets the price. There are also various hybrid approaches that combine fixed prices for a period with floating later on, and floating prices at some price levels with a price floor or a price ceiling or both [38].

Carbon tax and ETS have two major differences: (a) whether the policy sets the price or the quantity of emissions, and (b) how the value of emissions is allocated. Under the carbon tax system, the government sets the price of emissions and captures the value of emissions in the form of tax revenues. In contrast, under ETS, the government sets the quantity of emissions and gives away a significant fraction of the value to emitters in the form of free allowances [40]. For ETSs, the GHG emission allowances can also be auctioned by the government and bring the government revenue. The value of GHG emission are traded and allocated in the market. In fact, an upstream ETS with allowances fully auctioned is equivalent in many respects to a carbon tax system [41].

Then there are the hybrids of transitional carbon pricing mechanisms. For example, the current proposal in Australia is to start with a fixed price on carbon (i.e. a carbon tax) for three years and then transition to an ETS, with a carbon price set by the market [29].

2.3. Comparisons

Researchers have debated extensively on the advantages and disadvantages of different GHG mitigation policy instruments for years [31–34,40–42]. Some [6,43,44] analysed the effectiveness of regulations and incentive instruments in the building industry. Other [40,45–53] focused only on the relative merits between a carbon tax and an ETS. No single instrument is clearly superior in all the aspects relevant to policy choice; the best policy instrument in one scenario can vary with the changing condition [32].

Table 2 summarizes the potential advantages and disadvantages of each policy. It should be noted that the discussions are about the generic forms and features of these schemes. Any particular scheme can have a number of variations in the details of scope and implementation in a given jurisdiction; some features may be taken out or revised to address a particular need or local issue. The appropriate authorities in a given jurisdiction consider a wide range of socio-economic, political, cultural, environmental and economic factors in deciding a scheme's details.

Under regulations, certain requirements limit the choices for consumers; while under incentive instruments, industry, commerce and government services can provide a range of choices of low energy cost products and services, if they meet the subsidy requirements from government.

Table 2
Advantages and disadvantages of policy instruments.

Policy instrument	Advantages	Disadvantages
Regulation	• More certain to meet relative targets or standards • Easier design and adoption issues • Straightforward implementation and administration • Familiarity for the public and government	• Economic inefficiency • Stultify the technique innovation • No guaranteed GHG emission mitigation outcome
Incentive instruments	• Easier and faster implementation • More flexible for companies • Long-term effectiveness	• Free-riding • Less effective when used alone • Economic inefficiency
Carbon tax	• Incentive for innovation • Cost-effective emission reduction • Low administration and transaction costs • Significant revenues • Stable explicit price on emissions • Less complex in design • Familiarity for the public and government	• Potential carbon leakage risk • No guaranteed GHG emission mitigation outcome • Difficult to set at the right tax rate • Negative effects on vulnerable members in society • Public suspicion surrounding the actual use of revenues • Potential rent-seeking activities • Easily opposed by the people
ETS	• Incentive for innovation • More certain GHG emission outcome • Easier politically to implement • Design flexibility • Easier international coordination	• High administrative and transaction costs • Unfamiliarity to the new concept • More complex in design • Volatility of emission allowances pricing • Potential rent-seeking activities

Most regulations can be easily implemented to meet certain targets and standards [34]. Some economists claim that regulations are economically inefficient [31,33,34,40,52,54] because they are not flexible for different situations and do not necessarily guarantee environmental outcome [34]. Using regulations alone leads to overhead cost for the government on designing regulations to cover all the GHG emission related activities as well as updating the most suitable technique information, making it difficult to achieve an effective GHG mitigation [55]. However, if the enforcements are ensured, regulations such as building codes are considered one of the most effective instruments to reduce emissions [6,43]. Regulations can also easily overcome some of the significant market barriers in the building industry and ensure new buildings to apply cost effective and energy effective designs [44]. Since similar standards or codes have already been used for many years by government agencies or regulatory bodies in many countries, the institutional costs are relatively low.

From the aspect of cost effectiveness and economic efficiency, however, regulations are not amenable to rapid and unpredictable technology evolutions and consumer preference changes [31]. Relying on regulations alone limits the potential for promoting sustainable development because this stultifies technique innovation because there are no incentives to go beyond what is required by the regulations [34,37,52]. In the building industry, regulations such as building codes or appliance standards usually lag years behind technical innovation [43]. Mandatory building codes could be ineffective, even when well-received by the industry, if the codes cannot be updated in time [56] or when they are poorly enforced. Lowe [43] has argued that regulation alone is unlikely to achieve significant GHG mitigation with the absence of clear and consistent price signals provided by direct carbon price policy instruments.

The effectiveness of voluntary incentive instruments is not easily assessed because they are often implemented within policy packages [37]. When used alone, they are usually less effective than regulatory and control measures [6]. Incentive instruments also usually cause free-riding problems which make few people take the policies [57]. However, incentive instruments have very positive effect on supporting other policy instruments and raising people's GHG mitigation awareness. They are very good choices for GHG mitigation when mandatory regulatory instruments are difficult to enact or enforce [58]. Some voluntary labelling programs have achieved great success such as the US Energy Star Program [59]. When the mitigation targets are small in scope, voluntary incentive instruments are much faster and more flexible than others. They can also be a good way for using the revenues from carbon taxes or allowance auctions to reinforce the long-term effect of other policy instruments [6]. People's energy consumption habits can also be influenced and changed by information and education campaigns or detailed billing and disclosure programs.

Some researchers think that a carbon tax is more efficient than regulation, for its comparatively low administration and transactions costs [34,53]. In addition to the potential environmental benefits of a carbon tax, it is also believed to reduce inefficiency in the tax system by redistributing the revenue to the public [60]. The significant revenues raised by carbon tax can be used for incentive instruments to enhance the environmental outcome, which become a virtuous cycle [34]. Carbon tax is not very complicated to design [54], and allows stakeholders in the building industry to predict the market more easily because they are familiar with the mechanism of taxation [52]. Carbon taxes can be used to promote early introduction of new technology [61] and kick-start a new market [43]. Carbon taxes can effectively impact people's awareness and behaviour for GHG mitigation in a long term [62] and help reinforce the effectiveness of other policy instruments such as regulations and incentive instruments [9].

However, by setting the price but not the quantity of the GHG emissions, carbon tax can become successful only in increasing government revenue, but be inefficient in reducing GHG emission. Also, it requires adjustment over time which may be complex and expensive for the government to set an appropriate tax level to achieve GHG mitigation objectives [52]. Setting an appropriate carbon tax rate requires the government to be fully informed of the mitigation costs, the economic growth, technology development, commodity prices and so many other factors, all of which

are difficult to assess [34]. The government could also incur political difficulty to set a carbon tax rate sufficiently high enough to mitigate the GHG emissions because people do not generally like taxes [34]. The public may also become suspicious of the actual intent of the revenues, imagining possible rent-seeking activities.

When marginal mitigation costs are uncertain, controlling the cumulative quantity of GHG emission by ETS is considered to be superior on efficiency grounds [40]. ETS could be easier to propose to the public compared to a carbon tax [40,49] and the amount and rate of GHG mitigation can be assured [52]. Free allocation can be used as an incentive to get the support of some key industries that would otherwise oppose the plan [54,63]. The two methods for distributing the emission permits, auction and free distribution provide more flexibility to design the trading scheme according to the real situation. It is an efficient and transparent way to distribute the GHG emission allowances by auction to those who value them most highly [46]. ETS in the building sector could encourage the adoption of energy efficient technologies throughout the industry value chain, because it provides equal weights to both energy supply and demand [64]. ETS can be applied both domestically (e.g. at industry level or at personal emission quota trading level) [65] and internationally (e.g. CDM or PCDM) [66,67]. International GHG mitigation collaboration is encouraged due to the simple, explicit and uniform auditing scope and rules of ETS.

Like other instruments, ETS also has some potential disadvantages. It may be more complex than a carbon tax and could lead to relatively high administrative and transaction costs [34]. If the distribution of the GHG emission allowances lacks public transparency and leaves considerable manipulation room of the processes for the powerful vested interests, rent-seeking activities may happen. Currently not many countries have appropriate GHG accounting system especially in the building industry. It may cause some failures such as excessive baseline or regulatory loophole in certain sectors [53]. Meanwhile, the unstable market price of emission allowances is a big problem for ETS, even though some researchers claim that the volatility and collapse of EU carbon price are mostly due to the Global Financial Crisis [52,68].

For the reasons discussed above and summarised in Table 2, a policy package that combines and complements the features of various instruments in their "pure" form [32] may be preferred. The same concept has been recommended in the building and construction sector after a study of the effectiveness of a wide range of emission mitigation policies in the sector in many countries around the world [6,21,43]. The previous discussions on the general advantages and disadvantages of different policy instruments need to be evaluated and re-considered to suit the current situation in different countries. For example, carbon taxes may be opposed by people in the U.S., but could be more easily implemented in China due to different political systems. The implication and impact of GHG mitigation policies to the building industry and its key stakeholders in two different contexts (like China and Australia, for example) need to be analysed in more detail.

3. Implications of the policies to the building sector of China

3.1. Review of building related GHG mitigation policies in China

As it's explained in the introduction, mitigating building related GHG emissions is critical in China. Understanding China's policy status for GHG mitigation in the building and construction sector is important for achieving the national mitigation plan. All categories of policies are reviewed and analysed to present the policy system for energy conservation, water saving, material saving, intensive land-use, or sustainable energy technique application, all of which are directly related to building related GHG mitigation. Two main databases were used for policy reviewing: the law database of Peking University and standard/code database of Wanfang Data, both of which are the most authoritative and frequently-used database for laws/regulations and standards/codes, respectively. Specific keywords were searched in the two databases to filter the policies related to building and construction. The keywords include 'green building', 'building and carbon emission', 'building and GHG', 'building and emission mitigation', 'building and energy conservation', 'building and carbon trade', 'building and carbon tax', 'building and carbon auditing'. The policies are all issued by the central government of China, currently active and updated by December, 2013. The reason that only policies issued by the central government were chosen is that the local policies are usually detailed and practical rules for the implementation of the central policies, due to the centralized policy system of China. About 244 pieces of policies in all are categorized and presented in Table 3.

A total of 140 pieces of policies are regulations, which are peremptory norms. Thirteen national laws and regulations, which cover different fields as presented in the table, have clauses to regulate the activities related to building's GHG emissions. Although an exposure draft of climate change law has been proposed in 2012, GHG mitigation has not been legislated in China, and even the term 'GHG mitigation' has still not been written clearly in the existing laws and regulations yet. About 96 government plans and rules related to building's GHG mitigation are found in the database. The plans and goals are the working objectives and guidance of the state department or various ministries of Chinese government. Sometimes the national plan has even the same importance and force as laws, such as the national Twelfth Five-year Plan [3]. To realize the plans and goals, multi-rules of the various ministries are made for energy conservation or GHG mitigation. GHG mitigation has been written in the national plan and related rules. Thirty-one mandatory standards and codes of building are the compulsory guidance for design and construction of buildings and appliances. Most of the standards and codes are to specify the technical detail of building's energy conservation.

About 100 pieces of policies are incentive instruments, including a variety of forms. Nine recommended building standards and codes and 35 certifications or labelling and their application are collected from the database, to provide the guidance of green building, new building materials and energy efficient appliance. Nineteen pieces of policies are about financial incentives, including special funds, subsidies and rewards, to encourage the application of new technologies in the industry. The applications of photovoltaic and geothermal technologies in the buildings are two mainly encouraged aspects of renewable energy utilization. Although still at the starting stage, energy performance contracting is a new method to promote energy conservation. Fourteen pieces of policies are about the promotion of technologies related to GHG mitigation, appearing in the form of *Category of Technology Encouraged to Introduce*. Pilot and demonstrated projects, industry parks, or even towns that adopt green or low carbon technologies are also new trends in energy conservation implementation in many areas of China, starting from 2012. It has been a new economic growth point of local government to attract investment, with the help of 'low carbon' or 'GHG mitigation' concept. Training of energy conservation and green building labelling by administrative order is new form of information incentive instrument, staring from 2013.

As presented in Table 3, direct pricing approaches, such as carbon tax or ETS, has not been officially applied national wide. Only pilot projects are the being experimented in a few cities.

Table 3
Main GHG emission mitigation polices in the building sector of China.

Policies	Contents and examples
Regulations (140)	**Laws and Regulations (13)** Urban and rural planning, construction, energy conservation, water resource, cleaner production, renewable energy Environmental impact assessment, cyclic economy, corporate income tax, energy conservation in public institutions Energy conservation in civil buildings, urban gas supply, environment management in construction projects **Government plans and rules (96)** Plans: government budget, city planning, energy structure adjustment, technology innovation of building materials and equipment Goals: energy conservation, GHG emission mitigation, science and technology development Rules: energy consumption monitoring and auditing, building materials recycling, reform of household water price, temperature control of air-conditioning in public buildings, city lighting control, urban heating supply, construction waste management, energy conservation in buildings of schools and hospitals **Mandatory building standards and codes (31)** Public buildings, high education campuses, commercial buildings, hospitals, libraries, stadiums, etc Air conditioning, heating and ventilation, indoor lighting, water supply and drainage, solar heating, sunshade Wall insulation, urban gas supply, urban heating supply, etc.
Incentive instruments (100)	**Recommended building standards and codes (9)** Indoor air quality, energy conservation switch, premixed concrete, cement, plate glass, ceramics, etc. **Certifications or labelling and their application (35)** Green civil building, green construction, green and low carbon town, green industrial building, household appliances **Special funds, financial subsidies and rewards (19)** Green building, energy conservation monitoring on government office buildings and large public buildings, New wall materials, renewable energy utilization, innovation on cement, energy efficiency in existing buildings Efficient lighting products, building waste recycling, new materials for wall insulation, energy efficient appliances **Energy performance contracting (2)** Energy conservation **Technology promotion and information provision (14)** Solar heating, photovoltaic power generation, geothermal energy, wind power generation, bioenergy New building materials, energy conservation and water saving equipment, water saving technologies Technologies for energy efficiency in existing buildings, building materials recycling **Pilot and demonstration (19)** Green building, green industrial park, low carbon province and city, photovoltaic building **Training (2)** Energy conservation and low carbon city, green building labelling
Direct pricing instruments (4)	**Clean development mechanism (1)** **Pilot of ETS (2)** **Pilot of carbon tax (1)**

There is also not specific operation guidance for the building and construction industry. Although it is still at the very beginning stage, direct pricing policies are development trend of the future, because establishing GHG emission trading market has been written in the national plan, as described in the Introduction.

According to the analysis above, the status of building related GHG mitigation policies in China can be summarized as: Most of the policies are not directly aiming to mitigate GHG emissions, but to regulate or encourage the activities related to GHG mitigation, such as energy conservation, water saving, etc. The concept of 'GHG mitigation' has been proposed and written in the national plan, but has not been widely implemented in the government management practices. Regulations and incentive instruments are widely used by the government. Direct pricing approaches are still at the pilot stage, but will be the trend of the future.

3.2. A green building case study in China

Although the building sector has one of the most potential for significant and cost-effective GHG mitigation, that it also has more mitigation barriers than any other sector [44]. These barriers include the well-known fragmentation in the industry, and specific factors such as economic/financial barriers, lack of appropriate production technologies, behavioural and organizational constraints, and information barriers [69]. The barriers are the reasons why variety of policies is needed for GHG mitigation in the building sector. Different cross-sectoral policy options have different implications to GHG mitigation in the building and construction industry. In order to point out future policy setting direction, the challenge is how to realize the latent potential of significant emissions reduction in the sector under the existing policy circumstance. The practice of green building is still at the primary stage, so statistical data is difficult to get. A case study is applied to disclose the effectiveness and deficiencies of the current GHG mitigation policies in the building sector of China.

The case building, named Nanhaiyiku 3, is located at Shenzhen, which is a south China city in hot summer warm winter zone. The building was renovated from a reinforced concrete frame structured plant building, and started running from 2008 as the headquarter of its developer—Shenzhen Merchants Real Estate Holdings Co., Ltd. The building after renovation has 5 floors above the ground and 1 floor basement. The gross floor area of the building is 25,024 m^2, including 16,259 m^2 air conditioning area.

Nanhaiyiku 3 is a high performance green building with multiple GHG mitigation technologies, such as high energy efficient air-conditioner, passive design, and renewable energy equipment. The building won Three Star Green Building Award in 2009, which is the highest level in the green building assessment system of China. The application of technologies helps the building perform well in energy conservation, but meanwhile leads to high incremental cost. The GHG mitigation effect and cost information were investigated and analysed, as presented in Table 4. Some assumptions need to be clarified in the case study:

(1) The whole life of the building is assumed as 50 years (commercial land use term in China). The incremental

Table 4
GHG emission mitigation effect and cost analysis of Nanhaiyiku 3.

GHG emission mitigation technologies	Specification	GHG Emission (t CO_2-eq)		Cost of the technology (Thousand Yuan)	Initial Incremental Cost (Thousand Yuan)	NPV of Incremental Cost during 50 years (Thousand Yuan)	Energy Saving per year (Electricity/ Natural Gas)	NPV of Energy Cost Saving during 50 years (Thousand Yuan)	NPV of Net Incremental Cost during 50 years (Thousand Yuan)	Unit Cost of GHG Emission Mitigation (Yuan/t CO_2-eq)
		Decrease	Increase							
High energy performance air-	**conditioner**	COP: 4, compared to ordinary COP: 3.2, life: 25 years	**7,664.4**	**/**	**7,090**	**5,180**	**6,637**	**180,475 kW h**	**3316**	**3321**
433.3										
Passive energy saving design		**5,687.6**	**4537.2**	**3,850**	**3,280**	**3,800**	**133,324 kW h**	**2450**	**1350**	**1173.5**
Natural ventilation and lighting	Aluminum alloy-glass atrium and ventilation chimney, 50 t aluminium per 25 years	5,687.6	2985.0	650	650	833	133,324 kW h	2450	1350	1173.5
Exterior shadings	Aluminium alloy panel, 26 t aluminium per 25 years		1552.2	1,200	1,200	1,537				
Vertical greening	Roof and wall		/	470	470	470				
Building envelope	Aerated concrete block and Low-E glass, compared to traditional lime-sand brick and white glass		/	1,530	960	960				
Renewable energy utilization		**2,871.6**	**70**	**1,660**	**1,610**	**2,063**	**/**	**1515**	**548**	**195.6**
Solar photovoltaic system	400 m^2 PV panel, life: 25 years	2,133	70	1,250	1,250	1,602	50,000 kW h	919	683	331.1
Solar thermal water system	Provide domestic hot water, 240 days per year, compared to gas boiler	738.6	/	410	360	461	6,661.3 m^3	596	– 135	– 182.8
Ground source heat pump	Auxiliary equipment for domestic hot water, 120 days per year									
Total		**16,223.6**	**4607.2**	**12,600**	**10,070**	**12,500**	**/**	**7281**	**5219**	**/**

structures' life is assumed as 25 years according to design codes of China. The equipment's life is assumed as 25 years according to product specification.

(2) Embodied GHG emissions of the incremental structures (e.g., exterior shadings, glass atrium) and equipment (e.g., air-conditioner, solar PV panel) are considered in calculation, as Incremental GHG Emission. The differences of the embodied GHG emissions between the replacing equipment (e.g., solar thermal water system and ground source heat pump) and traditional equipment (e.g., gas boiler) are ignored, due to lacking of information.

(3) The discount rate during the 50 years of the building's life is assumed as 5%. Inflation and price fluctuation of energy and equipment are not considered due to high uncertainty. Price of commercial electricity is 1.0064 Yuan/kW h. Price of commercial natural gas is 4.9 Yuan/m^3. Incremental management cost and rising of the rent caused by green technologies are not considered, due to lacking of information.

3.3. Effectiveness and deficiencies of the current GHG mitigation policies in the building sector of China

The application of new technologies has prominent effect on GHG mitigation during the 50-year life of Nanhaiyiku 3, as presented in Table 4. However, almost all the NPVs of net incremental cost of the new technologies during 50 years are positive. It means that the payback from the saving of energy cost cannot cover the incremental cost (initial instalment and replacement) of new technologies even during 50 years. Solar thermal water system and ground source heat pump are the only technologies from which energy cost saving can cover initial instalment and replacement incremental cost. It is also the reason why these two technologies popularize easily in the market. As reviewed in previous section, policies have been made to overcome high upfront investment costs and long payback period barriers. Effectiveness and deficiencies of current policies are presented in Table 5.

Two current policies can be applied on Nanhaiyiku 3 to subsidize the incremental cost of GHG mitigation technologies. One is targeted to the application of solar photovoltaic systems. The other is targeted to labelled green buildings.

Table 5
Incremental cost of Nanhaiyiku 3 burden on the stakeholders and the effectiveness of the policies (Unit: Thousand Yuan).

	Solar photovoltaic system	GHG emission mitigation technologies
Developer		
Initial incremental cost	1250	10,070
Developer + Owner		
NPV of incremental cost during 50 years	1602	12,500
User		
NPV of energy cost saving during 50 years	919	7,281
Developer + Owner + User		
NPV of net incremental cost during 50 years	683	5,219
Current policies		
Subsidy: 20 Yuan/WP	792	792
Reward: 80 Yuan/m^2 for three star green building	/	2,002
Possible additional policies		
Subsidy/reward: 7.3 Yuan/WP	287	/
Labelling/detailed billing/ education	/	6,312
Carbon tax/ETS: 83 Yuan (10 Euros)/t CO_2-eq	171	964

The subsidy (792 thousand Yuan) on solar photovoltaic system of Nanhaiyiku 3 is more than the NPV of net incremental cost during 50 years, but less than its initial incremental cost (1250 thousand Yuan). It means that if the developer operates and uses the building, the subsidy and energy cost saving will cover the total incremental cost during 50 years. However, if the developer just builds and sells the building without obtaining the benefit of energy saving, the subsidy from the government cannot cover the initial incremental cost on solar photovoltaic system. Additional policies might be applied to remove the barriers, if the GHG mitigation can be priced and allocated to the developer, and a little more subsidy (7.3 Yuan/WP) from the government (maybe from the local government of Shenzhen).

The subsidy and reward on the GHG mitigation technologies of Nanhaiyiku 3 are about a half of the NPV of net incremental cost during 50 years (5219 thousand Yuan) and a quarter of its initial incremental cost (10,070 thousand Yuan). So even the developer owns and operates the building to keep the benefit of energy saving, the investment on the entire green technologies still cannot be recovered during the whole life of the building. Considering the possible income from priced GHG mitigation, the investment recovering gap is still big. Nevertheless, not liking the application of single renewable energy technology, green buildings with comprehensive green technologies not only provide the benefit of energy saving, but also improved health, comfort and productivity of the residents [70]. The advantages of green buildings should be reflected at the price or rent, compared to traditional buildings with the same location and function. If the incentive policies (e.g., labelling, detailed billing, education) would help the market recognize the benefits of green building and increase the value of the property (6.312 million Yuan, take Nanhaiyiku 3 as an example), the developers will balance the initial incremental cost of constructing a green building. The scene is conceivable because 6.312 million Yuan is only about 5% of the total investment of the project (120 million) and even less percentages of the property' price. The case study of Nanhaiyiku 3 shows that under the current policy circumstance of China, subsidies and rewards are effective for some single GHG mitigation technology, but far from enough for comprehensive green technologies in the high performance green building. The green building cases in China are more like pilot for propaganda. Nanhaiyiku 3 is occupied and operated by its developer as headquarter, for example. Before the value of green building has not been fully recognized by the market and reflected in the price and rent, developers would not has significant interest to invest broadly on the GHG emission technologies, even with the current economic incentive policies and the possible direct pricing policies.

4. Future direction of GHG mitigation policies in the building sector of China

As discussed in the previous sectors, deficiencies of the current GHG mitigation policies exist in the building sector of China. Huge potential for GHG mitigation need to be captured by policy instruments from the government of China in the following direction.

4.1. Balance the costs and benefits of the stakeholders

The application of GHG mitigation technologies in the building provides benefits for all the stakeholders. Developers get reputations and keep their positions in the industry. Tenants get energy

cost saving and healthy and comfortable living experience. The society and government get a better environment. Unfortunately, the costs of GHG mitigation technologies split disproportionately to those who benefit from it. For example, building tenants may wish to improve the energy efficiency of the building to reduce their energy bills. However, the building owners and developers who have the power and finance to make the decision to implement energy efficiency and low emission technologies and measures may not see the benefits for themselves [6]. Consumers do not want to spend or cannot afford to purchase energy efficient but expensive equipment upfront; known as the high first cost barrier [71,72]. If the energy price or the carbon price is set up too low, the tenants would also not intend to renovate the buildings or update the appliances because operating costs are only a small proportion of the renting costs [73]. The case study of Nanhaiyiku 3 demonstrates that energy cost saving and compensation from the policies such as subsidy, reward and even direct pricing schemes are not sufficient to cover the high initial incremental cost of the developers.

Some researchers [27,74,75] have noted the utmost importance of stakeholders' involvement in designing GHG mitigation policies. The involvement of a cross-disciplinary team from all the stakeholders at the earliest stages and throughout a green building project can improve the chances for financial success to overcome the first cost barrier [72]. According to policy-making theory and past experience, many aspects such as finances, resources, industries, taxes and environment should be taken into account during the policy design process [76,77]. Multiple policies should be implemented aiming at different stakeholders to remove the current barriers of GHG mitigation in the building sector of China, as presented in Fig. 1. Regulations set the minimum environment requirement for the developers and suppliers to declare the political determination on GHG mitigation. Economic incentive instruments such as subsidy or rewards are direct incentives for the developers and suppliers to overcome economic barriers. Informative incentive instruments such as labelling, detailed billing and education help the owners, tenants and other stakeholders recognize the value of green building to improve the acceptance of the society and culture, as well as to increase the economic value of green building indirectly. Direct pricing policies, as cross-sectoral policies, have broad influence on balancing the cost and benefit of all the stakeholders and the entire society for GHG mitigation, and enhance the effectiveness of other policy instruments as well, as discussed in Section 2. Appropriate packages of policy instruments can balance the costs and benefits of the stakeholders to overcome the barriers of GHG mitigation in the building sector [21,70].

4.2. Policies directly aiming to GHG mitigation

Quantitative investigation of the effects [78] and cost-benefit implications [79] of GHG mitigation policies in a broader sense have been identified as needed before the practical introduction of any policy. Compared to the energy/water conservation policies, policies directly aiming to GHG mitigation induce mature methodology for auditing GHG emissions of buildings. Normative GHG auditing methodology increases the market confidence in the value of GHG mitigation. Well-informed market circumstance is also one of the essential conditions for the implementation of carbon tax or ETS. In general terms, the effectiveness of policies for GHG mitigation is assured when the key stakeholders in the industry have confidence in the jurisdictional authorities, and are knowledgeable and supportive of the proposed schemes [80]. Furthermore, embodied GHG emissions from the production and transportation of the materials and equipment may be ignored by energy/water conservation policies. For example, although passive energy saving design is one of recognized effective way to mitigate building GHG emissions [70], the mitigation effectiveness may be greatly reduced if materials are not chosen properly. Plenty of high energy-intensive and emission-intensive aluminium alloys has been used on Nanhaiyiku 3 for atrium, ventilation chimney and exterior shadings, leading to great quantity of embodied GHG emissions as presented in Table 4. As a matter of fact, the result will be much better if aluminium alloys is replaced by steels.

The development of a possible "GHG burden-cost" model by direct GHG mitigation policies is required to project the relative distribution of significant GHG emission contributors to the total carbon footprint and significant costs to the total project cost before the start of the physical building construction or refurbishment. Then the costs and benefits of the stakeholders can be split according to reasonable basis. A database of large samples needs to be established to set the GHG emission baselines and the cost

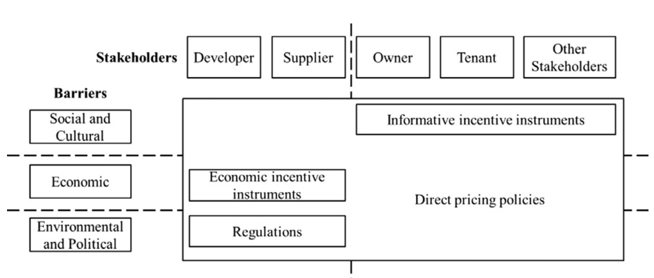

Fig. 1. GHG mitigation policies aiming at different stakeholders in the building sector.

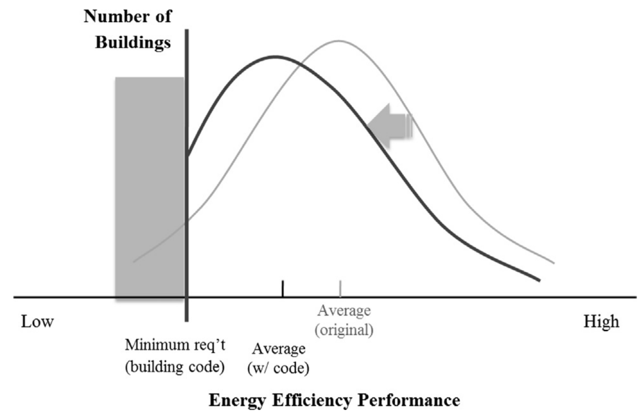

Fig. 2. Illustrating the potential implication in the building industry of a regulatory requirement alone.

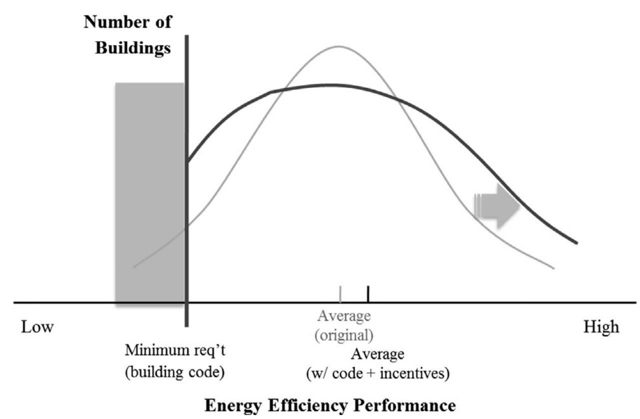

Fig. 3. Illustrating the potential implication in the building industry of a policy package including regulations, incentive instruments and a direct carbon pricing scheme.

baselines of different functional buildings in different climate zones. Then, a policy impact model could be developed and used to support the decision makers when choosing the most cost-effective policies or policy packages to mitigate GHG emissions in the building sector.

4.3. Holistic and comprehensive policy pathway

The implementation of GHG mitigation policies is still at the primary stage in China. Proper pathway needs to be followed to arrange the multiple policies efficiently and effectively. Considering the possible range of energy efficiency performance of a building population (from low to high), Fig. 2 shows that without a minimum performance requirement (i.e., as a building code requirement), a typical building population's energy performance will assume a normal distribution, or a bell curve (grey line). In the presence of a regulatory requirement alone, which disallows poorly performing buildings, both the market and the industry will attempt to just meet the minimum requirement, in the process shifting the curve to the left potentially along with the population average (darker bold line) as well. Without any incentive, this does not encourage the investors, the clients and/or the builders to construct high energy efficiency performance buildings or develop new energy efficiency techniques for buildings.

If the government uses regulations, incentive instruments and a carbon pricing mechanism, all supported by an effective education/awareness program, not only is the lowest energy efficiency performance buildings eliminated, but also high energy efficiency performance buildings and energy efficiency R&D are encouraged (Fig. 3). The investors and developers will more likely be able to build facilities that have higher energy efficiency performance and receive both financial and non-financial benefits at the same time. The average building energy efficiency will also likely shift towards the high performance end of the curve. If this shift is sustained over time, this in turn, will allow an opportunity to "raise the bar" on the code-allowed minimum performance (i.e. shifting the minimum line towards the right). The process can be hastened and the market transformed by a combination of regulations, incentive instruments and a carbon pricing mechanism appropriate to the jurisdiction and local situation. This is essentially the same concept promoted by industry organizations that develop and implement green building rating systems.

5. Conclusion

This paper reviewed the key features and implications of a broad range of GHG emissions mitigation policy options on the building and construction sector. The main policy classifications and specific schemes that were discussed and compared in detail were (a) indirect pricing mechanisms – specifically, regulations and incentive instruments – and (b) direct pricing mechanisms – specifically, carbon tax and emissions trading scheme (ETS). The potential advantages and disadvantages of the generic forms and features of each policy scheme were discussed and compared. It was noted that any one particular scheme could have a number of variations in the scope and details of implementation because the appropriate authorities in a given jurisdiction consider a wide range of socio-economic, political, cultural, environmental and economic factors in finalizing a scheme's details. The review of the status of building related GHG mitigation policies and the case study of Nanhaiyiku 3 proved that mix implementation or packages of indirect and direct pricing mechanisms are the trend of future, with balanced costs and benefits of the stakeholders, explicit GHG mitigation aim, and holistic and comprehensive implementation pathway.

Acknowledgments

Acknowledgments are addressed to the Chinese Academy of Engineering (CAE) for funding the authors' research (Grant No. 2010-XZ-10), and China Merchants Property Development Co. for the kindly support in the research.

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